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DEPOSITION OF THIN, TAPERED ALUMINUM FILMS

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DISCLAIMER

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ABSTRACT

A tapered film is defined as one in which the thickness changes monotonically in a given direction. The experimental setup and procedures to obtain a tapered aluminum film with a linear thickness gradient are described in this report.

INTRODUCTION

We define a tapered film as one in which the thickness changes monotonically in a given direction. A tapered film is needed for making a magnetic thin film with special properties. It has been known that the coercive field, H_c, of a magnetic film depends on the surface condition of the substrate. A rough surface tends to increase the H_c value of a film, which means that a higher external field is required to switch the film from one magnetization to another. It is also known that the surface condition of a metal film depends on its thickness. As a rule, the roughness of a film surface increases with thickness. This is particularly true with soft metals like aluminum, gold, and silver.

In our design of a magnetic thin-film, surface-current sensor, a film with graded H_c values is required. Such a magnetic property can be obtained by deposition of a magnetic film onto a substrate with graded roughness. A tapered aluminum film offers the desired graded-roughness surface for a graded H_c film. The technique to obtain a tapered aluminum film is described in this report.

GENERAL ANALYSIS

The method we used to deposit a tapered film was modeled after a technique developed by Prof. S. Matsushita of Osaka University. A line source of aluminum is used in conjunction with a static shutter, which is placed midway between the source and substrate and thus shadows part of the substrate. The scheme is shown in Fig. 1.

As a first approximation, the film thickness at any point of the substrate depends on the length of the line source observable from that point. For an example, point A "sees" the total length of the line source, while point B, which is the midpoint on the substrate, sees only half of the line source. Thus, the film thickness at point B will be half of that at point A. By simple geometrical considerations, it can be shown that the thickness gradient of the film deposited under the proposed configuration is linear. The approximation is good when the substrate is located at a reasonable distance from the line source.

The final design of the deposition fixture was influenced by other considerations than those discussed in the previous section. The surface condition of the metal film

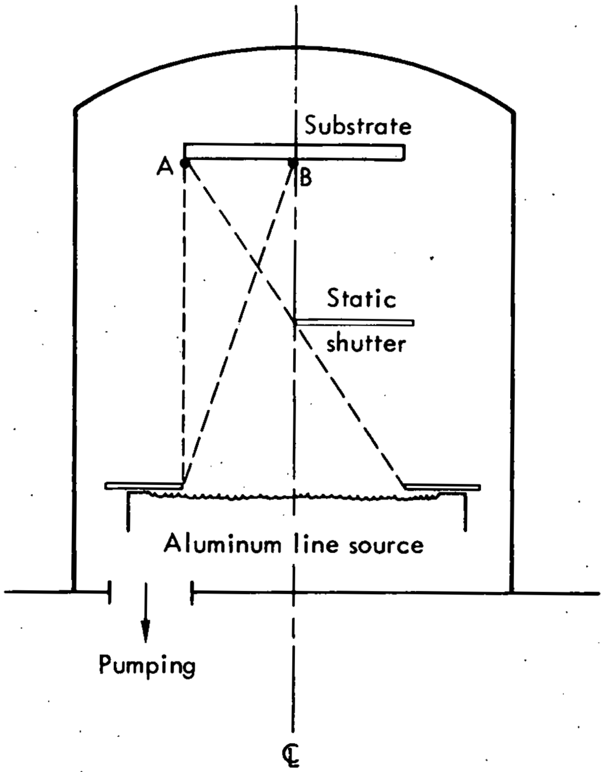

Fig. 1. Schematic of deposition configuration.

can be affected by the incident angle of the metal vapor upon the substrate, the condensation rate, and the substrate temperature. In our design, we tried to keep the angle of incidence uniform across the entire substrate by using as large a substrate-to-source distance as practical, and by employing as short a line source as dimensional uniformity allows. To achieve temperature uniformity across the length of the substrate, we designed our substrate holder so that the glass substrates are supported from the sides, thus avoiding heat-sink effects at the ends of the substrate. The substrates are heated by radiation, which generally offers good temperature uniformity. The deposition fixture is shown in Fig. 2.

EXPERIMENTAL PROCEDURES

The aluminum deposition took place in an oil-diffusion pumped system with a suitable liquid-nitrogen cold trap. Precautions were taken to minimize the partial pressure of O_2 and H_2O in the vacuum chamber.

Standard glass microscope slides, each cut to 25 × 38 mm (1 × 1-1/2 in.), were used as the substrate material. The slides went through a cleaning procedure which included the following steps:

- Acetone degreasing.
- Distilled-water bath.
- $CaCO_3$ paste rub.
- Distilled-water bath.
- Methyl alcohol bath.
- *n*-Propyl alcohol vapor-degreasing and dehydrating step.

At the end of the cleaning steps, the slides were mounted immediately on the substrate support and the vacuum system was pumped down to 0.133 mPa (10^{-6} Torr). The substrate heater was turned on to raise the substrate temperature to 450°C before it was allowed to cool to ~250°C for the aluminum deposition.

We used a standard wire line source, consisting of three 0.51-mm (20-mil) tungsten wires and one 0.51-mm (20-mil) aluminum wire, for the aluminum deposition. The aluminum line source was heated to a red glow for 0.5 hr with the substrates shuttered, as a cleaning step before the actual evaporation. The evaporation rate was typically 10 nm/s (100 Å/s), and the thickness gradient can be controlled from 0.8 to 3.9 nm/mm (200 to 1000 Å/in.) by adjusting the total evaporation time with the movable shutter. A new aluminum line source was used for each evaporation to insure repeatability from run to run.

EVALUATION

The thickness gradient was determined by an optical densitometer. The densitometer was initially calibrated with an aluminum film whose thickness was measured by an optical interference method. The tapered film was mounted on a micropositioner whose linear

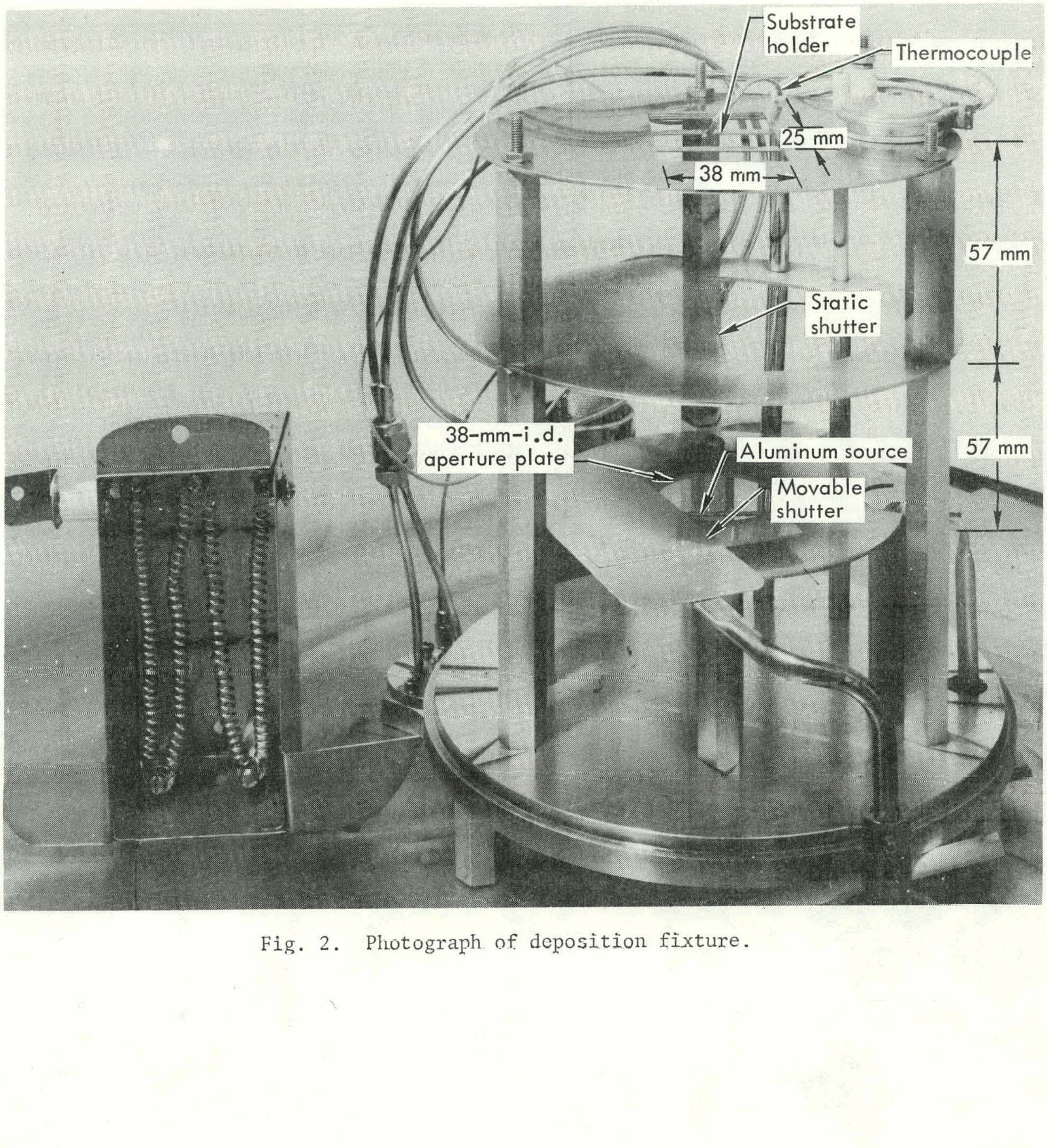

Fig. 2. Photograph of deposition fixture.

displacement was indicated by a voltage reading taken from a sliding resistor. The light transmission through the film was measured by a photodiode and read in amperes. A simple computer program was written to give a direct plot of thickness versus position from the voltage and current readings. Figure 3 shows a typical plot from a computer printout, indicating the thickness gradient of a tapered aluminum film.

It should be emphasized at this point that the positioning of the static shutter is very critical. A slight deviation from the crossover central position, as indicated in Fig. 1, will result in a nonlinear thickness gradient. At the beginning of the project most thickness-gradient plots assumed a slanted S shape, as shown in Fig. 4. After some analysis, we concluded that the position of the static shutter was responsible for this shape. We moved the static shutter 1.5 mm from the original position and thus successfully corrected the nonlinearity in the thickness gradient of these tapered films.

In conclusion, the present facility can produce tapered aluminum films with a linear thickness gradient that is controlled by total evaporation time. However, we have not yet introduced enough mechanical control in the movable shutter to enable us to predetermine the gradient for each deposition.

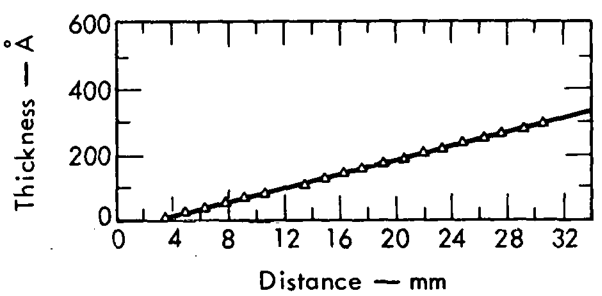

Fig. 3. Typical thickness vs distance plot of a tapered film.

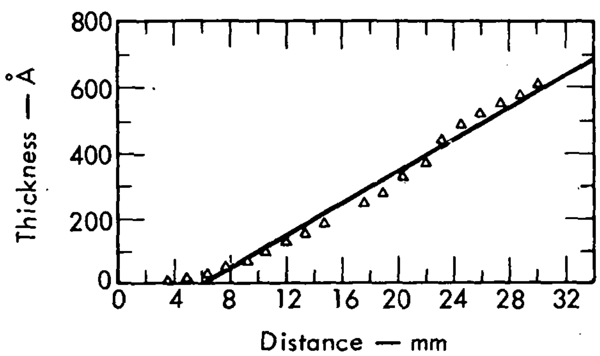

Fig. 4. Nonlinearity in the thickness gradient of a tapered film.

ACKNOWLEDGMENT

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